Can MEMS Accelerometers be used to Directly Monitor Relative Fracture Movement?

Introduction:
Currently the fracture or limb lengthening of any long bone is monitored using pain measures, radiographs and limb weight bearing. All these qualitative measures are inaccurate; radiographs provide little information of the fracture site due to un-calcified callus tissue. Excessive fracture movement (1 mm+ [1]) can lead to delayed healing (up to 7 weeks longer [2]) and mal-alignment (up to 19% of cases, [3]). However, if removed too early, there is a real risk of re-fracture due to insufficient callus stiffness (up to 8% of cases, [4]). Furthermore, there has been some speculation as to whether mal-aligned tibia can lead to the development of osteoarthritis due to load changes in the knee. Ideally, identifying excessive movement of the fracture early can allow the fracture to be easily manipulated by adjusting the fixator.

An accurate method of quantitatively measuring fracture movement in vivo is needed to address this problem. The aim of this study is to investigate whether MEMS accelerometers can be used to accurately monitor movement directly in an externally fixed tibia fracture in vitro.

Methods:
Five 4th Gen Sawbones tibia bones were used to fix an external ‘Ilizarov’ ring fixator (n=2) and an external unilateral fixator (n=3) (Fig. 1). The fixators were inserted using a custom-made rig to eliminate ‘Ilizarov’ ring fixator (left) and the significance of tensioned wires in the unilateral fixator.

Fig 1: Two external fixator designs, ‘Ilizarov’ ring fixator (left) and unilateral fixator with accelerometers attached (right).

Accelerometer data, machine displacement and machine loads were logged at a rate of 1k/s. The accelerometer data was filtered by taking the Fast Fourier Transform (FFT) to quantify the frequency distribution of the signal and a low pass filter was used to eliminate background noise. The filtered accelerometer data was integrated twice to derive the displacement of the moving fracture. The calculated displacement was plotted against the Instron machine displacement.

Results:
The calculated displacement from the accelerometers showed very good correlation to actual fracture displacement (machine displacement) from 0.5 mm to 2 mm. There was an inverse correlation between fracture movement and displacement error, in a typical tibia unilateral fixation, the displacement errors were approximately 2.5% at 2 mm, 6.6% at 1 mm, 10% at 0.5 mm and 30% at 0.1 mm (fig. 2).

Discussion:
For successful fracture healing, two biomechanical pre-requisites are required; the fracture gap must be less than 0.5 mm and fracture motion must be 1 mm or less. The use of accelerometers in fracture healing have been unsuccessful previously as they have been used on the external fixator frame as an indirect measure of healing by either measuring vibration changes in the stiffness of the fixation system, which gives an indication of healing. However, these measures are qualitative and have not been correlated directly to fracture healing.

In this study, the use of high precision MEMS accelerometers to directly measure fracture movement is possible. Fracture movement of up to 1 mm, the physiological limit for healing, can be accurately measured (2 mm displacement with 2% accuracy), which is critical to prevent delayed healing, mal-alignment and risk of re-fracturing. Further work in miniaturizing the accelerometer and monitoring tilt is needed to develop this technique, which has the potential to make an important contribution to long bone fracture healing and limb lengthening procedures.

This technique is currently being used to assess the significance of different external fixator configurations commonly used in the ‘Ilizarov’ ring fixator and the significance of tensioned wires in the unilateral fixator.

Significance:
This work demonstrates the successful use of accelerometers to measure relative axial fracture displacement directly. This approach can be applied to reduce the number of delayed healing (non-unions) and mal-alignment (1 in 5 cases). Thus the need for a measurement method could impact on hospital costs, healing time and possible long-term musculoskeletal damage.

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References: